



THE CHEMICAL PRINCIPLES OF THE ROTATION OF CROPS.

PRONOUNCED BEFORE THE AMERICAN AGRICULTURAL ASSOCIATION, MARCH 4th, 1846, BY

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MR. PRESIDENT AND GENTLEMEN :

IT is necessary to premise this memoir by explaining that the Executive Committee had expected a communication from another gentleman and did not until a late hour throw the burden upon me, but my desire to gratify them has induced me to hazard the criticisms of the Association—tempered, as I know they will be—by the circumstances of the case. I have selected the subject of the rotation of crops partly because opportunities have fallen in my way to witness some facts which are commonly overlooked by writers on this topic, and because I regard it as a question of pure chemistry. I propose to search after general principles only, for if these can be determined, particular cases or the rotation suited to any district of country will be determined by a little consideration. This is moreover the only way whereby the subject can be discussed so as to be of utility to the whole country, the agriculture of which it is the object of your association to advance. A local rotation is hampered with considerations of expediency, with the price of land and of labor, the merchantable crops, the profit or loss of grazing, which offer obstructions to reaching any generalization; but whereas every crop and agricultural process is profitable in some part of our widely extended country, it is proper that such considerations should be dismissed, and introduced only in reaching particular cases. I know that in this day practical disquisitions are considered superior to all others, but if we make no effort to group facts scattered abundantly around us, the art can never advance. Your Association has the noble object in view of reaching principles in agriculture, and therefore I have no hesitation in presenting a theoretical memoir, the design of which is to attempt the deduction of the principles of rotation.

I. The Object and Necessity of Rotation.

That no doubt may arise of the object to be gained by systems of rotation I will advance a definition which may guide us in the following discussion. The object of a rotation is the production of the greatest profit in crops with the least exhaustion of the soil. The views entertained by practical men on the subject are however by no means fixed; in many parts of the country it is imagined that the only condition of a rotation is that the same plant be not cultivated annually, and that a succession of corn, wheat and oats is as much a system of rotation as any other plan—it is indeed a rotation, but not a system.

How far there is any practical necessity for rotations is also a point in much doubt. We are often assured by good farmers that given crops as corn, wheat, hemp, have been grown in certain districts from time immemorial. These are exceptions to a general rule and of no force whatever; they prove that there are spots on the earth's surface of extraordinary fertility, or, what is more frequently the case, that in such districts there is some cause of reparation, by freshets, irrigation, or the washings of adjacent hillsides. Wherever the fertility of new lands, which results from the growth of forests or accumulation of uncut grasses for centuries, is exhausted and the soil reduced to a state similar to the subsoil, it is necessary to adopt some means to increase its yield, either by manures or a system of rotation. That this condition is ultimately reached in uplands will be readily granted; the only point worthy of further consideration is how far a rotation will economize manure already in the soil in new lands, or manure added artificially. This is the immediate subject of the memoir.

Experience and analogy have led men to adopt rotations wherever agriculture has been practiced for a length of time. Experience has fully demonstrated that no plant will continue to luxuriate under ordinary circumstances for an indefinite period. To this rule trees are only an apparent exception, for they submit in time to new species when left in a natural state; they live indeed for centuries because by the great development of their roots they penetrate year after year into new strata of soil; but it is well known that in northern forests the birch and maple follow the pine, and in more temperate regions the pine succeeds the oak and allied genera.

Analogy is remotely a guide to rotations in the case of forests, but if we observe the phenomena of vegetation on new lands it becomes extremely instructive. The planter of the south-west makes haste to cultivate cotton on his new lands, because, for a few seasons he is not overwhelmed with grasses, but is called upon to combat annual weeds easily overshadowed by his crop. If a portion of new land be left waste we discover that a succession of plants invades its surface and not certain species, we find that however convenient the seeds may be, the plants of the first year give place in

time to new genera. To this point I have paid particular attention in Virginia, and find that however the species may vary in different soils, there is a sequence of natural families sufficiently apparent. Where the land is remarkably rich, the plants first developed are species of the families Chenopodiaceæ, Solanaceæ, Polygonaceæ—these give place to Malvaceæ, Compositæ, and Umbelliferæ; and finally species of Leguminosæ, Rosaceæ, and Gramineæ succeed. It is not asserted that other families are absent, but these are so fully developed as to be characteristic of the vegetation. This natural succession differs with the latitude, soil, and degree of moisture; but whatever may be the families, it is sufficiently apparent that the plants of new soils, or rich weeds as they are called, give place sooner or later to those of the barrens. Nor is this the only evidence of a natural rotation. After a season when the roots of grasses have produced a mat of vegetable fibres, is it not well known that the meadow becomes infested with wild onions, buttercups, (*Ranunculus*,) thistles, and other weeds, which, if not exterminated, soon overwhelm the grasses? Hence the prudent husbandman adds ashes or lime, and scarifies his meadows; for by these means the roots are rapidly decomposed, and the soil brought back to a state of composition favorable to the development of grasses: or if he be conducting a rotation, he ploughs the meadow, and thus acquires by art a natural coat of manure, of great service to such cultivated crops as, like the Chenopodiaceæ, require a soil rich in organic matters.

II. *Explanation of the foregoing natural rotation.*

The difficulty of making certain plants grow after each other in the same soil, was said to arise from the mutual repulsion of plants, and explained by VON HUMBOLT, PLENK and DE CANDOLLE, by reference to the experiments of BRUGMAN and MACAIRE. These naturalists discovered that the root of a plant growing in water, throws out a dark mucilaginous fluid which they called its excrement. Thus the excrementitious deposit of any plant is supposed to be inimical to the growth of its species, and also to some others; but may on the other hand be of service to an entirely different family. DE CANDOLLE saw in these reputed facts the explanation of rotations, which he therefore resolved into the art of discovering such a succession of crops, that each might flourish on the organic remains of its predecessors. Clean fallows were also commended as a means of hastening the decomposition of excrementitious matters.

But it is neither satisfactorily shown that excrementitious matters accumulate in the soil nor that they are inimical to the growth of the species. MACAIRE, BRACONNOT and others have failed to obtain positive evidence of such dejections, when a soil was employed instead of water, and ALFRED GYDE states that plants are benefitted by watering with a solution of their excrementitious

matters. Some, as BOUSSAINGAULT, go so far as to regard the dark mucilaginous matters said to be exuded by roots in water as the effect of a diseased action, denying the excretion, but this cannot be maintained, for amphibious plants as mints, cress, *Myosotis palustris* and other species, which are not placed in an abnormal situation when growing in water, yield this substance. The experiments of GYDE appear also explicit on this point. If we are to receive the theory of DUTROCHET, that the penetration of the soil fluid through the roots is a phenomenon of Endosmosis, there is a necessity of admitting the passage outwards of a portion of the elaborated sap, which GYDE states to be identical in composition with the excrementitious matters collected by himself. That none should be obtained from sand, or soil, under certain circumstances, is not surprising, for the exposure of the exuded matter, over a large surface and in contact with oxygen absorbed from the air, would rapidly change it into a new body capable of escaping the ordinary tests—in the same way that alcohol by mere exposure over an extended surface is rapidly converted into acetic acid by oxydation. Although it is premature to deny that a portion of elaborated sap does escape from the root of some plants, it is very evident that this does not create a deposit injurious to the future growth of the species and is not the principle on which rotations are to be devised.

The natural succession of plants is connected with the presence of organic matter in the soil. The richest weeds which first occupy the surface having the greatest necessity for it, and thus through successive groups to the grasses and forest trees which grow well without any portion in the soil. Other elements of fertility being present, the Chenopodiaceous and allied families thrive only in such localities as yield azotized matters, since they cannot grow without a supply from the soil. This surmise is sanctioned by the obvious presence of organic matters in the soils where they grow, and by the fact that some species exhale ammoniacal gases, but it is fully established by the experiments of BOUSSAINGAULT. This chemist grew clover, peas, wheat and oats in a soil completely destitute of organic matter and supplied them with distilled water only; the clover and peas were found to double their azotized matter during growth, whilst the oats and wheat gained none whatever. As there was but one source of azote present, the atmosphere, it is apparent that the former have the capacity of supplying themselves therefrom, whilst the grain plants are altogether dependent on the soil. Hence in a soil charged with organic matters, rich in azote, those plants which require a supply by their roots will grow freely, and so far exhaust it in time as to render it unfit for the species, which is succeeded by an intermediate class, and finally by the Graminæ, Leguminosæ, and others capable of subsisting on aerial azote, and so far from exhausting, adding it to the soil. From this function of plants, we see an explanation of the natural rotation, and what is of more moment, a means of adapting our succession of crops to the accumulation as well as removal of azotized matters.

III. The Rotation of One Principle.

BOUSSAINGAULT, PAYEN and the majority of French agriculturists estimate the value of manures by the amount of azote they contain; and there is not, for general purposes, a more useful test. Therefore the great object of manuring is with them the application of azote to the soil, and the great—if not the sole—principle in rotations the economy of this body. As some crops gain azote from the air, as clovers and grasses, these serve an important purpose in such a plan by concurring with manure in supplying food for the cerealia and such crops as exhaust the soil. According to BOUSSAINGAULT we should therefore, in a system of rotation, introduce crops in such order that after the manure a highly exhausting plant as wheat may come and this be succeeded by others of less affinity for nitrogen, and again by those which draw their supplies from the air and are the ameliorating crops of this class of agriculturists. The soil now recruited by clover, lucern, grass, etc., will bear another azotized crop and the system is at an end.

There is something charmingly simple and plausible in this rotation of one principle, and its author has done much to establish it by appeal to practice. It is, moreover, identical with the natural rotation observed in new lands, and thus appears to challenge opposition. But there is a capital difference between any artificial and the natural rotation, in this particular, that in the latter case the plants die on the spot and are not removed hence, and whatever exhaustion arises from removing the crop is arrested. Our corn, wheat and oats not only draw azote from the soil but other bodies, and these are entirely withdrawn from the spot, whilst only the azote is removed by the natural succession of plants. Of the inorganic or saline matters much more is often withdrawn, that of azote; hence, whilst the new land is exhausted of but one element of fertility, the cultivated field loses more.

The greatest objection to this view of rotation is its opposition to experience, for it will be seen that a system, perfectly proper, according to this theory of one principle is inadmissible in ordinary practice. No one who is acquainted with the subject would expect much from the following succession: manure, corn, oats, beans, buckwheat, clover, wheat—yet it is a system in which the azotized matter of the manure would be well economized and the soil rather enriched in this respect. But the farmer knows that such a succession of seed crops would soon render his land valueless, whether organic matter were accumulated or otherwise. The one principle rotation is not, therefore, acceptable to the understanding of theoretical nor to the experience of practical agriculturists.

IV. *The Precepts of Practical Writers.*

The points advanced by practical writers as THAER, LOW, STEPHENS and RHAM, as the principles of rotations are of considerable moment, especially in the field, but are no more than surmises for the most part. They may be resolved into the three following assertions and precepts:

1. That each plant requires a particular food and should therefore be repeated at as long intervals as possible.

2. That seed crops being peculiarly exhausting are to be interchanged with green or forage crops and roots.

3. That plants which require hoe tillage, being cleaning crops, should follow those which are sown broadcast and encourage weeds.

In these positions we recognize the imperfect observations of farmers; each one is true within certain limits, and excepting the last, which is only a practical expedient, it is impossible through them to reach any general principle. That each plant requires a particular food is an assertion merely which, so far from carrying conviction, is altogether denied by some practical men and, whether true or false, is beyond the means of these writers to prove. The second assertion, that seed crops are exhausting, is sustained by experience; but in what way they are exhausting is not stated, and without this information the assertion is of little value. As we have remarked, the third position is a practical expedient only, because both seed and forage plants may be hoed crops, as corn, beans, cotton—tobacco, turnips, cabbages.

Hence the precepts of practical writers resolve themselves into the two points, that the same and allied species should be cultivated at as long intervals as expedient and that seed plants are to be as seldom introduced as possible. Both these positions are of practical value, but they do not merely labor under the defect of conveying no precise information, but may be used in forming schemes of rotation of no economy whatever. Thus the following plan is perfectly conformable with these precepts, but very objectionable.

Manure, corn, tobacco, oats with clover, wheat, beans.

or, as in the rotation for clay lands, by MR. RHAM,

Manure, roots, oats with clover, beans, wheat.

In the first a seed crop is followed by a foliage crop, but both of these are exhausting; in the second, beans are succeeded by wheat, both exhausting, but — and this is the imperfection of such arbitrary precepts — the exhaustion in every case is not of the same kind or degree. We are informed that certain crops are exhausting, but not of what; they impoverish the earth, yet we

have no knowledge imparted of what substances. It is not enough to say of manure, for this is a compost of all the bodies necessary for plants. If we still further advance the speculations of practical men and assert that the exhaustion is of organic matter or humus, the position is denied by the second precept, for seed crops such as beans are exhausting whilst they require little humus — whilst on the other hand, many forage plants as cabbages, turnips, beets, are not seeds crops, but exhausting. We do not deny that excellent rotations devised by practical men do exist, but we do deny that every rotation based upon the foregoing indefinite precepts is necessarily good, and if they be no guide without the assistance of experience gained at great cost and by separate observations in the field, they are worse than useless. The defect of the precepts rests in this, that we are not informed in what respect the food of different plants varies, nor in what particular seed crops exhaust the soil. The apologists of the system may assert that these are remote facts not within the reach of the propounders, but this being the case the time has now arrived when a closer approximation to truth may be made and the former precepts abandoned or improved by modern investigation.

V. Of the Exhausting Qualities of Crops.

The soil may be exhausted to such a degree that it will cease to produce certain forage plants without the introduction of a single seed crop. If we enrich any field so that it produces tobacco and follow this crop by cabbages, turnips, flax, taking no seed from either, we speedily reach a period when none of these plants will yield a remunerating crop. This is one kind of exhaustion, but it is not complete exhaustion, for corn, wheat, oats, beans and clover seed may be obtained in good quantity from the same field. On the other hand, a few crops of hemp seed, linseed, corn, oil grains, wheat, will run down the land to barrenness; but this exhaustion is altogether different from the preceding; it is, in truth, the specific exhaustion produced by seed crops, and it matters not which are the seeds. Hence there are two distinct kinds of exhaustion well known to practical men and it behoves us, who desire the advancement of agriculture, to make the line of demarkation between them bold and distinct. There are other kinds of exhaustion to which we shall refer presently.

In a paper I had the honor of reading before the Association last year, I made a thorough examination into the nature of the exhaustion of lands by seed crops. The object of the communication was to prove the following points:

1. That all seeds contain an excess of phosphoric acid, amounting usually to thirty-five or forty per cent. of the entire ash, nearly the whole of the ash being in many cases phosphates; this was demonstrated in the case of corn, wheat, beans, hemp seed, flax, peas, cotton and other

plants. It was also shown that the straw and haulm seldom contain more than one to three per cent. of phosphoric acid, this substance being segregated in the seed. For the analytical evidence of these positions I beg to refer to the Farmer's Dictionary, in which the admitted analyses of all plants hitherto examined will be found.

2. That phosphoric acid is the least developed of all the mineral bodies of the soil, being seldom present to the extent of 0.5 per cent. and usually less than 0.1 per cent., in good soils.

3. That many soils containing from five to twelve per cent. of humus are known to be steril.

4. That the amount of phosphoric acid removed by given seed crops far exceeds that removed by the ordinary forage crops, being often five times as great.

The evidence of these positions was set forth at length in that communication and is therefore not worthy of repetition. The principle which I believe was fairly reached, and admitted, was that seed crops exhaust the soil of phosphoric acid — the deprivation of which is easily perceived, even in the best lands. It is not necessary for me to advance further evidence of this fact before your Association.

If it be admitted that phosphoric acid is segregated in the seeds, it is evident that the exhaustion effected by foliage plants, as tobacco, cabbages, flax, hemp, etc., not intended for seed and of the root crops, with perhaps the exception of turnips, is due to another cause. The experiments of BOUSSAINGAULT and our own observations on natural rotations will now throw light on this other kind of exhaustion. Some plants draw all their azote from organized matters in the soil, others from the air; some families of plants appear only on rich soils and around dung-hills, whilst others inhabit the mineral earth destitute of organic matters. It is evident that phosphoric acid has nothing to do with this peculiarity, for none is removed from the soil, the dead plants restoring it; there is a diminution only in volatile matters or in the azotized products of the decaying organic matter. Let us cultivate a few crops of cabbages or tobacco on a rich spot of land, how soon will the organic matter disappear! Practical men may tell us that this is because the crops are hoed and the soil exposed to the sun, but this is not the cause; the hoeing improves the plant because by introducing air it hastens the decomposition of the organic matters of the soil or assists the fixation of atmospheric nitrogen. (*See Mulder. Journ. fur. Pract. Chem.* XXXII. p. 344). When putrescent manures are added to tobacco, potatoes and similar crops, the indication is to furnish azotized matters, and is altogether different from the object in view when it is added to wheat and certain grain crops. But if this point requires further evidence we may appeal to those plants which exhaust the soil differently under different circumstances. A flax crop raised for its fibre exhausts the soil of azote and may be followed by corn or beans, but if it be allowed to mature seeds it

exhausts the soil doubly of azotized matter and phosphoric acid, and cannot be succeeded by corn except in the richest soils. Hemp raised for fibre may be cultivated many years in a soil containing much humus but the seed crops are rapidly exhausting.

Hence we have crops which exhaust the soil of azotized matters — crops which remove an excess of phosphoric acid — and grasses and clovers, cut before bearing seeds, which exhaust the soil of neither of these essential bodies but on the other hand enrich it in organic matters. Many cultivated plants, as corn, wheat, cotton, hemp, flax, cabbages, etc. raised for seed, exhaust in both respects and are therefore peculiarly expensive crops. With this amount of information, based on experience and several hundred analyses, we have the means of rendering intelligible the precepts of practical writers on the succession of crops.

Precept first resolves itself into the principle, that plants exhaust the soil unequally in respect to azotized matters and must therefore be so adjusted that the most exhausting should recur as seldom as possible.

Precept second. Seed crops, which exhaust the soil of phosphoric acid, are to be interchanged with herbage plants, which do not remove as much of this important substance.

These directions have now assumed a definite form and are an explicit guide to the well informed farmer ; he at once perceives that there are, over and above the precepts of expediency as to hoed or cleaning crops and deep rooted crops, classes of plants which differ remarkably from each other in their action on his fields. 1. Seed crops which exhaust the soil of azote. 2. Seed crops which do not exhaust the soil of azote. 3. Exhausting forage and root crops. 4. Crops which neither exhaust the soil of humus nor phosphates, but renovate the azote. With this amount of knowledge he can shape a fair system of rotation, whatever may be his crops—he can introduce indigo, cotton, tobacco, corn, bene, oil plants and many others which are not found in the arbitrary tables given by LOW, THAER, and STEPHENS or falsely placed by BUEL and ARMSRONG. But if we recur to our definition of the object of rotation—the production of the greatest profit in crops, with the least exhaustion of the soil or manure—we find that there is yet something wanting in the principles of rotation. In the fourth class above, we have plants which neither exhaust the soil of azote nor phosphoric acid ; it now becomes necessary to know in what respect they do exhaust it, so as to satisfy the economical condition of impoverishing the soil in the least degree.

VI. *Plants Exercise a Natural Affinity for Specific Saline Matters.*

It has been already shown that the seeds of cultivated plants cannot be matured without phosphoric acid, and we find upon examination that this is not the only instance in which a distinct

partiality is evinced by vegetables for certain mineral bodies. Chemical analyses and the observations of naturalists assure us of this fact. It is notorious that the plants of salt marshes are distinct from those which are found near fresh waters. In Switzerland, the appearance of certain species of clover is known to indicate marl. The plants indigenous to clays, sands or calcareous soils are distinct, and if they be not instantly recognized it arises from the fact that most lands contain an admixture of all the mineral substances essential to fertility. From the analyses of chemists, now extended to several hundred, we find that there is also evidence of the affinity of plants for certain bases; thus it is sufficiently clear that Composite, Umbelliferous, Amentaceous, Gramineous and Chenopodiaceous plants prefer potash; Leguminous, Rosaceous, Solanaceous and Rubaceous plants affect lime; the families of Cruciferae, Asphodeleae and Liliaceae select soda. Every person knows that oaks, maples and walnuts yield more potashes than pines. The study of this subject is not, however, completed; there are many points to be considered which tend to involve the inquiry in difficulty. It may be said that DAVY was the first who drew attention to this topic, in a chemical point of view, in the cases of gypsum and clover, oats and silica. Little had been done to this time until LIEBIG resuscitating the views of DUNDONALD and DAVY showed the affinity of several plants for certain bases. He enumerates grass, oats, wheat, barley, tobacco, peas, potatoes, clover, corn, turnips and the Jerusalem artichoke. This kind of classification has occupied much of my attention for several years, and has been dwelt upon in my lectures in the University, and for the reasons I have already advanced I beg to extend the number of plants to the families above enumerated, in which several are also placed in a situation different from that of LIEBIG; the subject is, however, far from decided and probably the exceptions to grouping in families may be greater than the advantages gained. Whatever grouping may be expedient, it is not to be forgotten that several circumstances are to be considered in making use of any analysis for the purpose of determining the place of a plant: these are—

1. That there exists an unquestionable isomorphism amongst many of the mineral bodies: thus—potash, soda, oxide of ammonium and hydrate of lime—lime and magnesia—sesqui-oxide of iron, sesqui-oxide of manganese and alumina—sulphuric and selenic acids—phosphoric and arsenic acids—are respectively isomorphous groups. Hence soda may replace potash; hydrate of lime may be present in place of either soda or potash. That this displacement or substitution does occur in nature is abundantly proved. Thus soda has been found to replace the potash of the oak in Long Island, on the sea coast. Marine plants, as the *salsosas*, transplanted to an inland situation are found to contain potash. Tobaccos from various sources, analyzed by BERTHIER, yielded potash as a base, whilst specimens examined by FRESSENIUS and WILL yielded sixty per cent. of lime and magnesia salts.

2. The different parts of the same plant yield an excess of dissimilar salts: the potatoe tuber contains eighty-six per cent. of potash salts — the tops sixty-one per cent. of lime salts. In the same way, the roots, foliage and seeds of other plants give indications of an affinity for different minerals.

Hence it follows that analyses will differ with the nature of the soil on which the plant has been produced, and with the part examined, or if every portion be examined with the part used in excess. As it is usual to publish the mere analysis without designating the soil, or variety of the plant, it is necessary in arriving at trustworthy conclusions to look somewhat further than this. Therefore, in reaching my position, I have kept in view two points — the natural habitat of the plant and the circumstances under which its produce becomes of great excellence. Thus in the analysis of the onion by FOURCROY and VAUQUELIN, lime salts predominate; CADET found sixty-four per cent. of potash salts in the garlic; but I venture to place the family to which the onion belongs (*Asphodelæ*) amongst the soda plants, because it is well known that asparagus, many kinds of onion and other genera are indigenous to the sea coast and salt marshes, and because the Spanish onion which excels all others is cultivated in lands irrigated by salt water. Cruciferous plants are soda plants characterized by a remarkable affinity for sulphur, yet in the analyses of the ashes of turnips and cabbages they appear to be potash plants, that base acting as a substitute; I arrive at the conclusion that they prefer soda, from the fact that cabbages and many other cruciferous plants delight in situations near the sea shore. A gentleman well known to this Association has recently shown that the grapes cultivated near the low salt plains of New-Jersey contain soda instead of potash salts, and are in consequence of a very inferior flavor. Another interesting case of the influence of the bases on the flavor of plants exists in the case of tobacco. The French government agents, finding that the tobaccos from the United States had become decidedly inferior to the old samples, submitted specimens to the examination of M. PELOUZE, who ascertained that lime salts predominated in the inferior specimens in the place of the potash salts obtained by BERTHIER.

In determining the place of a plant in the saline groups, I have for the most part selected the ashes of leaves as the true guide, because, in the first place, the leaf is the important organ of vegetation in which the sap is elaborated and the future growth of the plant provided for; and secondly, because there is reason to suspect that some part of the saline matter of the roots may be, like that of the bark of trees, a refuse portion. It is true, that in the case of potatoes, the leaves are not removed and the saline matters of the tubers only are taken from the ground, and therefore economically considered this saline matter should be estimated, but the marked effects of lime in the culture of potatoes, on the tubers as well as the leaves, makes it evident that this base is the one that is essential, and that, although potash salts are given in the analysis of SPRENGEL, it appears to arise more from the mixed nature of the soil than the predilection of the plant, and the lime salts would

be found in the tubers as well as in the leaves, on calcarious soils. If the view of RASPAIL be correct, that the presence of saline matters in tissues is the essential of their organization and the true source of their distinction from the mere proximate principles of which they are composed, it is a necessary consequence that the organizing portion of the plant — the leaf — should contain the essential saline matters, without which, or other isomorphous substitutes, it could not be developed nor carry on its functions; and if the leaf does not flourish the plant cannot attain perfection. In this view of the case, it is proper to determine the situation of plants in the saline groups according to the analysis of the leaf, if they be cultivated for foliage or roots only, unless the amount of mineral matter removed by the roots be very much the greatest.

The influence of cultivation is not to be overlooked in grouping plants. Under natural circumstances all the grain-bearing plants require little azotized matter, but from the development which many, such as wheat and barley, have acquired, they have become azotized plants, and are not to be maintained in their present state without a large supply of this food made to the roots. Many garden vegetables are also of this kind; the cabbage in nature consists of a few tough leaves and inhabits soils of ordinary fertility on the sea side; its present luxurious development, by which it attains a weight certainly a hundred times greater in several varieties, is the result of supplying food to the root in tillage, and if the supply be diminished the characters of the variety are soon lost and the vegetable degenerates.

The following table will show the position of most cultivated plants, so far as evidence exists at present. The conditions under which the classification has been made should be borne in mind.

Plants requiring much azote in the soil,	Seed bearing	Lime,	{ Hemp seed, Cotton, Hop, cultivated Peas.
		Potash,	{ Corn, Madia, Wheat, Rice, Oats, Barley.
		Soda with Sulphur,	{ Rape seed, Colza, Mustard seed, Linseed.
	Foliage or root crops,	Lime,	{ Tobacco, Potatoes, Hemp, Indigo, Madder.
		Potash,	{ Sugar cane, Carrots, Parsnips, Mangel-wurzel, Beets, Spinach.
		Soda with Sulphur,	{ Turnips, Kohlrabi, Ruta bage, Cabbages, Onions, Asparagus.
Plants requiring little or no azote in the soil,	Seed bearing	Lime,	{ Field Beans, Pindars, Vetches.
		Potash,	{ Rye, German and Polish Millet, Buckwheat.
	Foliage or root crops,	Lime,	{ Pomaceous fruits, Lupius for fallow- ing Clovers, Spurry, Lucern, Sain- foin; all cut before seed.
		Potash,	{ Meadow Grasses. Jerusalem Artichoke.

Thus the table presents ten groups of plants to be employed in a rotation, which are variously exhausting of saline matters and exhausting or ameliorating as respects azote.

VII. On the Chemical Principles of Rotation.

In purchasing a farm we do not merely aim to gain possession of a superficies on which plants may be set: the object is to obtain such a natural compost of mineral and organic matters as may afford nutriment to plants, in the most perfect manner and for the longest time. If, in a particular locality, there be but one or two remunerating crops our object is to secure a soil which will best feed these. The affinities of plants have been already set forth, whereby a judgment may be formed of the fitness of the farm. In converting the minerals of the earth into crops we must adopt such a system as not to exhaust it too rapidly in one respect, without drawing any resources from another part. If in a situation where every crop is marketable, we adopt a series which takes from the earth only phosphoric acid, we do ourselves injustice by turning to no advantage the purchase of azote, lime, potash and sulphur in the soil.

By a well digested succession of crops we economize each body of the soil, converting it into money without loss or improvidence. As we have paid for every kind of plant-food in the earth we incur a loss by allowing any part to remain unappropriated. Instead of cultivating one crop and going abroad for manure in a year or two, by cautious economy, we obtain that manure at home. The soil presents us with a magazine of saline matters or plant-food, for the most part in an insoluble condition. Annually, the dews of evening and showers act on the insoluble materials, and dissolve a portion: by tillage and judicious management more is rendered available. If the crops do not appropriate all the parts rendered soluble; some percolate into the soil and are wasted. The exposure of the earth, and most crops, rapidly deprive it of organic matter, and it becomes unfit for the growth of many, and diminished in fertility for all plants. By carelessness much waste is thus brought about, and this likewise occurs if manures be used. Farm-yard manure is but a condensed fertile soil, it merely wants the sand and clay which are for the most part mechanical components of lands, and contains the saline and azotized matters constituting the plant-food. Guano represents the soil also, but the fertilizing ingredients are here extremely condensed.

When a good farm, or stable manure, or guano is purchased, we obtain azotized matter, phosphoric acid, salts of lime, of potash, of soda and compound, of sulphur, all of which will be lost to the surface tillage, by volatilization, or percolation in solution, if neglected; or all of which may be reaped in harvests if judiciously managed. This end is to be accomplished only by a suitable rotation, which is therefore, as we have heretofore asserted, an economical expedient only.

As we are engaged in discussing general principles, it is no part of the subject to consider the case of particular soils and manures; but it may be remarked with regard to these, that if the soil be peculiar, as calcareous, green sand, etc., or the accessible manures, as gypsum, marl, refuse fish, be not perfect composts, the rotation must be adapted to the case and does not require the elaborate system necessary for more complex soils and manures. We must either give such land the complex character of the most fertile soils, an expensive process, or adapt the crops to meet its defects. But an opinion is not to be hastily formed of the nature of any soil; we may readily ascertain if clay or sand predominate, if it be rich in organic matter or lime, but before an accurate conclusion can be reached we must be certain that it does not contain alkaline silicates, phosphoric or sulphuric acid, and these are not readily detected even in the richest soils.

When the land or manure contains every kind of plant-food in legitimate proportion, with no great excess of any, as is the case in good soils, the problem to be solved is the system of rotation which shall economize all these ingredients. As to the question of market, it is local; nor do we consider whether grazing be adopted or the crops directly sold, as this in no way interferes with the principles in hand. If we sell oxen, sheep or wool, we deprive the soil of certain of its saline and organic matters, and the rotation must be filled up so as not to waste such as are not sold in this form. If we employ complex manures, true economy does not alter the rotation, each crop is enlarged, but the substances removed from the land or lost will be similar. It may be well to consider one point more fully. If a short rotation be adopted to improve the soil, a time will arrive when the improvement being effected, a new class of more exhausting plants may be introduced, but these are in all cases introduced according to the same principles. There is nothing gained after the soil has reached a certain tilth in continuing the improving system, the object is now to reap our reward; but to do this in such a way that at the end of the rotation the soil shall not have fallen below a certain standard, it is then to be refreshed either by manure, meadow grasses, lucern or other suitable means not now under consideration, but belonging to the topic of improving the soil, and not that of rotations.

The farm having reached its high point of tillage, by suitable means, is now to be cropped for profit, and reduced thereby to a certain practical standard—what are the general principles on which this cropping is to be conducted? Obviously by a system of rotation, during which every saline and azotized matter that becomes soluble is removed, and no part is wasted. This can be accomplished only by introducing such crops as have severally an affinity for the various kinds of plant nutriment, and adapting them to the proportion of food present in the soil. Phosphoric acid is the rare ingredient of soils and manures, excepting guano and bones, the former of which contains 12 and the latter 25 per cent. of this body. Next after this is the azotized matter which forms a small

per centage of vegetable mould (0.5 to 3.0 per cent.) and is therefore to be removed cautiously. Sulphuric acid is present to some extent in all soils, abounding most in ancient marls and gypseous formations. The supplies of lime and alkalies are very much greater than any of the preceding bodies; the former attaining 10 and the latter 4 to 5 per cent. in rich alluvial lands. The extent to which we may remove these in a rotation is as their probable amount in the soil, which may be taken in general terms after the following rates per cent., in a perfect alluvial soil. Phosphoric acid 0.20—azotized matter 0.25—sulphuric acid 0.10—alkalies 2.00—lime and magnesia 5.00. In estimating the consumption we must know the amount and kind of bodies removed with each crop. The difference of average crops in this respect is remarkably striking, and the subject has been fully detailed in my lectures in the University. It may be proper, here, to adduce by way of illustration, a few cases. A crop of wheat of 25 bushels with straw removes 123 lbs. of inorganic matters, consisting of about 12 lbs. of phosphoric acid, 90 lbs. of silica, 15 lbs. of alkaline salts. A crop of lucern of two tons removes 425 lbs. of mineral bodies, of which about 250 lbs. are lime, 20 lbs. sulphuric acid. Eight hundred bushels of beets remove about 360 lbs. of ashes, of which 316 lbs. are alkaline salts.

It would be tedious and out of place to read here the tables upon which these calculations are made; it may be enough to state that they have been made, and that they form one of the necessary items of knowledge in constructing a perfect rotation. In addition to this, every expedient used by practical men, as the introduction of cleaning crops, green fallows, depasturing fall crops, the employment of roots, etc., are to be attended to in carrying out the design of the rotation—the economy of the mineral and organic aliments of the soil. These expedients do not however, constitute principles to be incorporated in the system, but are only practical adjuncts to be used or otherwise according to local circumstances.

Recurring to the foregoing explanation of the two precepts deduced from practical writers, we find that they are sustained by the attraction of particular plants for certain aliments, and are therefore two principles for the government of rotations. To these we now add a further precept, that in the employment of foliage or root crops, to economize phosphoric acid, such as succeed each other, should differ in respect to their affinity for lime, alkalies and sulphur. Thus we have attained the following principles:

1. Seed crops exhaust the soil of phosphoric acid; and are to be introduced at intervals from each other as remote as may be expedient.
2. Certain plants require a large proportion of azotized matter from the soil; and are therefore to follow the application of the manure or to open the rotation in rich soils.
3. Certain crops recruit the soil, as respects azotized matter; and are to be employed after its partial exhaustion.

4. Foliage and root crops differ in their affinities for saline matters, and the amount which they remove from the soil ; and should be so introduced in a rotation as to economize those which are rendered soluble. These are also ameliorating or exhausting as respects azotized matters, and are to be selected in such a manner as to fulfill the indications of the second and third principle.

It may be proper to test the accuracy and practical value of these principles, by examining a rotation of undoubted value. For this purpose I have selected the Norfolk system, because it is well known to be the most successful ever devised ; it has raised entire counties in England from sterility to the highest prosperity, and has extended wherever the soil and market were available. It consists of the following succession : first year, manure, followed by turnips ; second year, barley sown with clover ; third year, clover, the first crop cut, then depastured and ploughed for wheat ; fourth year, wheat, succeeded by manure and turnips, as before. In this system the manure is followed by the plant requiring the most azotized matter, this is also a soda and sulphuric acid crop. Barley, the second crop, requires very much less azotized matter and exhausts the soil of only a limited amount of phosphoric acid and potash. This is succeeded by a lime plant, clover, which recruits the azotized matter and loosens the soil by its long roots. Wheat, which completes the rotation, is a potash and phosphoric acid crop, requiring a medium supply of organic matter. This rotation, when we consider the soil and the manures used, the former siliceous and the latter farm-yard compost and bone earth, is a perfect embodiment of the foregoing principles. Reached entirely by experimental means, it is strictly conformable with science ; and is a striking illustration of the correctness of the doctrine, that rotations form a chemical study, which, originating with CHAPTAL, has been maintained to our day.

In conclusion, I beg to present a few instances of the application of these principles in the construction of rotations. The plants proposed for the several soils are indicated by the probable excess of mineral matters and phosphoric acid therein. The crops which may be substituted are placed vertically under the principal plant. There is in the rotation for clay soils, a mechanical impediment, arising from the difficulty of keeping them in tilth, which influences the plan ; and in sandy soils, also, it is necessary that too many hoed crops be not introduced, and that grazing be practised to render the soil compact. The rotations given are applicable north of Carolina.

I. A ROTATION FOR GOOD MIXED SOILS.

	First Year.	Second Year.	Third Year.	Fourth Year.	Fifth Year.
Manure—or the soil in the highest condition. {	Corn.	Oats, Clovers, Rye, Grasses. Barley,	Clovers, Grasses.	Potatoes.	Wheat, Carrots, Oats, Parsnips. Barley.

II. A ROTATION FOR RICH CALCAREOUS SOILS.

	First Year.	Second Year.	Third Year.	Fourth Year.	Fifth Year.
Manures, etc. {	Potatoes, Hemp, Tobacco.	Wheat, Clovers, Barley, Beets.	Clovers.	Corn, Beans.	Oats. Rye.

III. A ROTATION FOR RICH SILICEOUS SOILS.

	First Year.	Second Year.	Third Year.	Fourth Year.	Fifth Year.
Manures, etc. {	Turnips, Rutabaga, Beets, etc.	Rye, Grasses, Oats, (Spurry.) Barley.	Grasses fed off, (Spurry, “ “)	Corn, Wheat, Buckwheat.	Jerusalem Artichoke, Rye.

IV. A ROTATION FOR CLAY SOILS.

	First Year.	Second Year.	Third Year.	Fourth Year.	Fifth Year.
Manures, etc. {	Corn.	Oats, Clover, Rye, or Grasses.	Clover, Grasses.	Potatoes. Beets.	Wheat, Barley, Oats, Beans.

